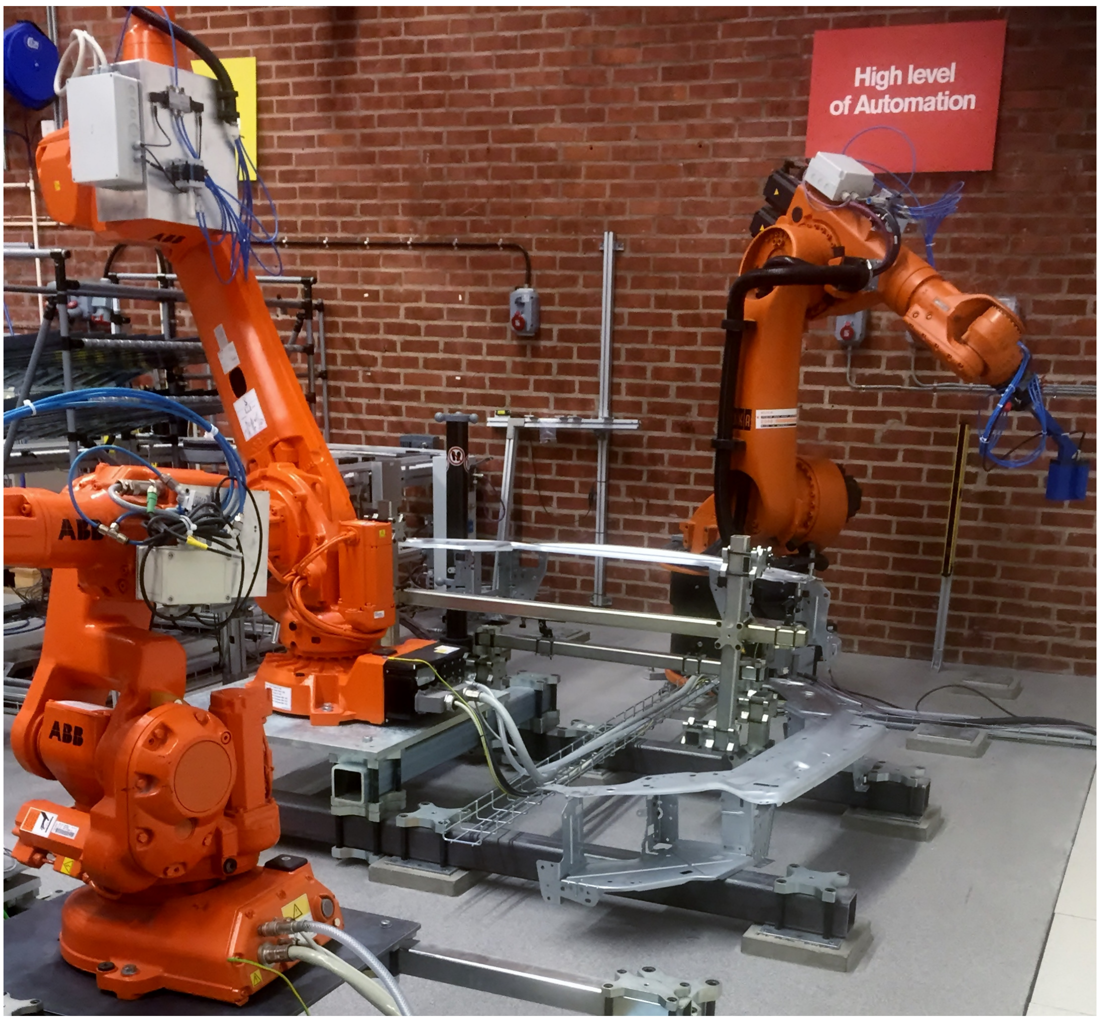
FFI

Automated Process Control BIW (AProC)



Project within FFI – Hållbar produktionsutveckling

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Content

1. Executive summary

All manufacturing processes have variation which may violate the fulfillment of assembly, functional, geometrical or esthetical requirements and difficulties to reach desired form in all areas. The cost for geometry defects rises downstream in the process chain. Therefore, it is vital to discover these defects as soon as they appear. Then adjustments can be done in the process without losing products or time. The project consists of five different work packages (besides a report package). These work packages address different areas which are necessary to fulfill the overall scope of the project – development of an intelligent robot based in-line measurement system including path planning and inspecting engineering applicable for the system. The system shall both be able to detect geometrical defects, propose adjustments and adjust simple process parameters. The project participants are experts in the different fields of the project scope and will be responsible for different WP.

Goals:

- Demonstrate functionality of effective measurement system and verification process
- Demonstrate functionality of CBR to detect and propose corrective actions for dimensional deviations
- Demonstrate functionality of flexible fixtures

Results: All of the above mentioned goals have been reached in AProC. These goals were defined for part one in this project. Part two will focus on connecting the different WP with an automated solution and then will goals be set for more industrial implemented solution. A continuation project will be applied for as a continuation project after reaching the goals in part one.

2. Background

Good and secured quality is vital for the Swedish automotive industry. All actors involved in the automotive industry in Sweden and therefore, projects which lead to increased quality is of vital interest for increased competitiveness for Swedish companies. Increased quality can be obtained in many different areas, this project focus on intelligent process automation control and geometry assurance. Examples of areas which are affected of geometrical deviations are: Product quality, Tire wear, Noise, vibration, and Sound (NVH), Problem with closing doors etc, Optical quality, Production disturbances, Increased cost due to large tolerance settings, Increased wear of production equipment, Scrap rate, Rework of parts

2.1 Process to Automate

In-line geometry assurance of parts is of vital importance for quality. The in-line control generates decision base for adjustment decisions, which can be both manual or case for automation. If the part is outside given tolerances, it is not possible to assemble it correct and requires rework.
Today, the in-line measurement process is too slow to verify all required features per part. The solution is to measure different features in continuity e.g. features are measured in different batches per product and after a certain amount of products, all features are measured. If defects are discovered, the products are taken out from the process flow and adjusted in separate stations. After rework, they re-enter the process flow.
Another solution is that a specified amount of parts are taken out from the process flow per batch and send to a measuring room for verification. If defects are discovered, the process line adjust their settings and the produced parts are traced and reworked. This is a very time consuming and expensive process and the risk for that defects parts are delivered to customers are significant.

2.2 Development need

In order to do the processes more efficient it would require ability to measure all features on all bodies and also possibility to correct faults in an efficient way. Parallel projects e.g. InRob are developing systems for automation of measurements for increased efficiency with target to be able to measure all required features in each body. However, the question of making the correct decision regarding required rework is not addressed. If the necessary rework could be divided between manual and automated rework, the process would be much more efficient and unnecessary rework can be minimised.
Today's fixtures being used in production is dedicated and welded. This causes changes in the system difficult to implement. This project will develop new flexible tooling that facilitates the adoption of product changes.

2.3 Case study

The task for this project would be to develop methods and tools to combine efficient in-line measurement with decision support system for manual or automated process adjustments or rework activities. A secondary task for this project will be to develop new flexible tooling technology to enable jig corrections derived from decisions on geometry adjustments. In order to increase quality and efficiency, it is necessary both to detect errors and take good corrective decisions. The case study will consist of building a demonstrator cell at Chalmers where a lab scale industrial corresponding system for in-line geometry verification and validation will be installed. This will be a system for quality validation together with algorithms for decision of best corrective actions. Depending on fault, automated or manual actions can be chosen and the decision will result in physical change of the jig supporting the product

Following issues will be addressed:

- Efficient in-line measurement system
- Process line in lab scale for system development
- Methods/algorithms for decision support of corrective actions
- Lab scale station for corrective action for demonstrator
- New flexible tooling to support jig changes populated from the decision system

3. Objective

3.1 Main issues

The competiveness for companies in Europe are depending on effectiveness and quality since the labor cost is relatively high. A key factor for achieving this is to have stable and efficient processes together with an efficient quality assurance process. Experiences shows that European production processes have an advantage compared to low cost countries regarding know how, tools and methods to produce high quality products to a competitive prize. In order to keep the advantage, development is necessary since low cost countries learn quickly and are eager to close the gap. In order to keep production in Europe an increase business opportunities, market shares etc., it is important to evolve our processes. This project addresses one such area, which is improved quality and minimise lead time and cost for corrective actions.

3.2Main reason for project

In-line verification in today's need to be more effective and automated process/product adjustments need to be developed. There is neither any methods available for decision support for suitable rework methods which increase quality and decrease lead time and cost.
On the market today, system exists for in-line geometry verification, but they have limited ability to verify all required features. Therefore, only selections of features are verified.
AProC is addressing these issues and trying to develop methods and tools for solving them.

4. Project realization

4.1 General project description

The project consists of five work-packages (WP) and a complementary work package for dissertation and report. Due to the level of innovation of the project, it will be divided in two parts. The first part is a concept study, where the new concepts shall be proven. This will be followed up by a demonstrator project (part two) where full functionality of the ingoing parts working together shall be proven. In the description of the work packages below, the different parts will be explained. Part one is included in this project and part two will be included in a follow up application depending on the results of part one. The functionality will be demonstrated in a demonstrator cell. Each work-package has a number of sub-areas as described below:

4.2 WP 1: In-line measurement

In previous projects, efficient methods and functionality has been developed for in-line measurements, both tactile and non-contact measurements. Next step has been to combine measuring system and robot system together with developing efficient off-line programming system. In phase 2 it development of communication for corrective actions will be included.

Goal (G1):

In this WP the deliverables are:

- A robot based measurement system for geometry deviances implemented in the Chalmers test cell together with inspection engineering system.

4.3 WP 2: Process evaluation

Process evaluation can be done in many ways. The methodology used in this project is based on Case Based Reasoning (CBR). This methodology contains building a database with relevant cases which can appear in the production process. Both diagnosis, action taken and outcome are documented. The system can then recognize and evaluate process outcome and find similar cases in the database and hereby recommend actions to solve the problem. In part one of the project, the functionality of CBR will be proven. In part two, the functionality will be implemented in the demonstrator.

Goal (G2):

In this WP the deliverables are:

- A methodology for CBR applied to geometry variations
- A system implemented in the demonstrator cell together with the measurement equipment.

4.4 WP 3: Corrective actions

Corrective actions are today mainly operator dependent. In order to decrease lead-time and loss of parts, it is necessary to either to guide the operator in which corrective action to take or raise the level of automation in these actions. Hereby, the time between error detection and corrective action will be minimized. Corrective actions can be defined in many ways dependent of the process, but a common factor for all is that the input to the systems which control the corrective action must be defined in a format which is suitable either for operator instructions following Poka-Yoke philosophy and are easy to perform

or for automation. In this work package, methods and tools will be developed for control of the suitable corrective actions, both generic and specific for the demonstrator cell. This WP will mainly be developed in part two of the project.
Goal (G3):
In this WP the deliverables are mainly in part two of the project (which is not part in this application). In part one, only a concept study will be done:

- Concept study of how corrective actions can be implemented in demonstrator cell.

4.5 WP 4: Flexible Tooling

Once the corrective action is decided in the system some sort of hardware must comply to make the process perform some physical action in order to change the configuration of the hardware. This project will develop flexible fixtures adapted for automatic adjustments. In part one of the project, the functionality of flexible tooling will be proven. In part two, the functionality will be implemented in the demonstrator.
Goal (G4):
In this WP the deliverables are:

- Concepts for flexible fixtures adapted for automatic adjustments.
- Physical evaluation in demonstrator of those concepts that fulfill the requirements of the process.

4.6 WP 5: Demonstrator cell

Chalmers has recently invested in a new Production System Laboratory (PSL) focusing on research on advanced automation and how people will work and cooperate in factories in the future. This project will use this laboratory as a base for building a test cell with automotive components, fixtures, metrology system and robots. In part one, the robot based measurement system will be installed and verified. Furthermore, the concept of flexible tooling will be prepared and proven. In part two, all the different parts – Measurement system, CBR, corrective action and flexible tooling will be connected and demonstrated in the demonstrator.
Goal (G5):
Build demonstrator cell were the ingoing results from the WP can be tested

- Demonstrate functionality of measurement system and flexible tooling as individual techniques.

5. Results and deliverables

5.1 In-line measurements

In order to have an efficient in-line geometry control which can measure all necessary types of features, a robot based laser system from Zeiss have been used (see figure 1).

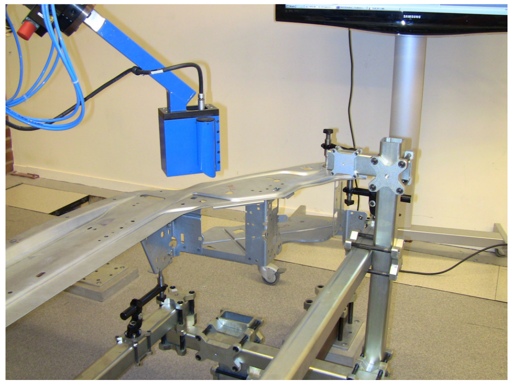

Figure 1. Measurement system

To be able to efficiently generate programs tools and methods have been developed for off-line programming of the robot based measurement system. Compared to old methods, the time for generating programs have been reduced significantly. Efficient method for defining features to be measured, Strategy to measure them, and the optimal path to reach shortest cycle time for the measurement cell has been developed. The outcome from the OLP is a complete set of program to control both the measurement system and the robot movement and their interaction.
The results have been implemented both in the demonstrator cell in Chalmers and in running production at Volvo Cars in Torslanda. For Volvo Cars, the saving in up to 1msek per program, a factor 5 in speed up for inspection engineering and a factor 6 regarding measuring time for a large station like floor complete.

5.2 Process Evaluation

We have in this work package built a database (case library) with 48 relevant cases which can appear in the production process, of these 10 repeatability cases. In the analysis of these cases we see that both the production line and measurement system is showing stable performance and the tolerances and variations detected are used by the CBR system to improve the performance. We have performed some cross evaluation amongst the cases, and we see that the same case always has 100% match and the correct adjustments are suggested by the system. When removing the identical case (100% match) from the system, the best matching case is according to experts the most relevant case to use in order to correct the deviation. E.g. if the known solution that solved the problem is an adjustment of a certain pin by -0.4, the CBR system identifies the most similar case (above 99% similarity) to be a case where an adjustment was made by -0.3 or -0.5 on the pin that solves the problem. Interpolation between cases will further improve the accuracy, but in the identified cases the adjustment of -0.3 and -0.5 would both bring back the produced part within the acceptable quality parameters.
The system also uses every added new measurements for every manufactured item to learn, increase the systems experience and performance. And the system can now handle cases for different manufacturing cells and for different manufacturing items and selects the relevant cases to work with which is an extension from the original system developed

in the ITEA Create project where it was not evaluated.
The performed evaluation shows that the system is able to find the most relevant cases and recommend adjustments if a close case exists. Since the system also knows the natural variation of the fixture and measurement system it also knows its limitations.
The interface for the system has been improved and adapted to the demonstration cell and it is also more general and it can identify geometrical defects and suggest adjustments.
We produced a user manual for the CBR system. The system is also able to detect drifting and can suggest adjustments also before geometrical defects are outside acceptable tolerances.

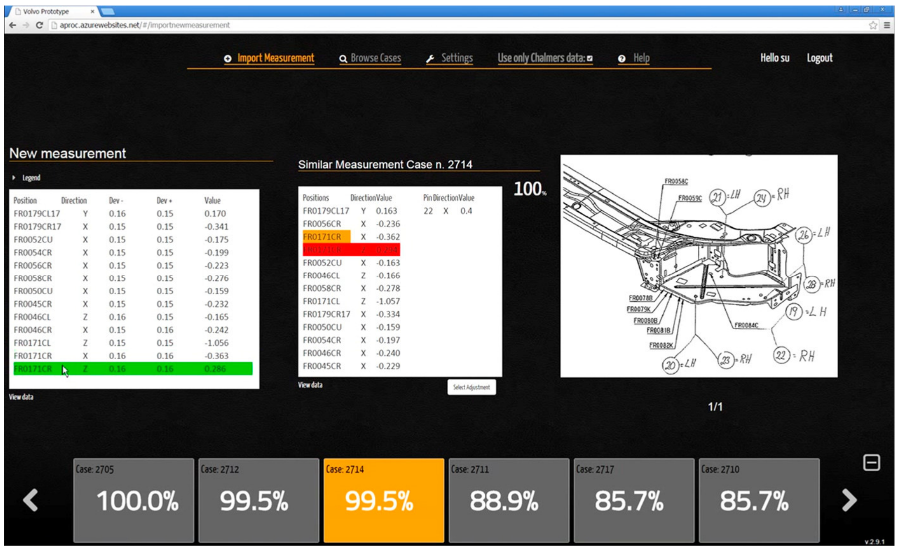

Figure 2. Example of user interface from the CBR adjustment system identifying most similar cases and suggesting adjustments based on case 2705

The CBR system is integrated with AProC Demo Cell and can handle the measurement files form the Zeiss measuring system. The system is also cloud based so now it will be able to handle more manufacturing cells at the same time. Once it receives the measurements from the cell, it will suggest appropriate adjustments if needed to correct and geometrical or esthetical defect, or adjustments to prevent the manufacturing of defect items. This will considerably reduce spillage of items that do not meet the quality criteria's of the assembly. It also enables early detection, often before any problems arise and suggest adjustments to keep manufacturing within given quality requirements. By suggesting adjustment based on all measurements and choosing the most optimal one, the system will after initialization and once it is used regularly it operation it will after a short while outperformed human operators with its accuracy. This will reduce operator time considerably and detach cell performance from dependability of operators skill level.

5.3 Corrective Actions

Based on experience from the chosen case, critical adjustment parameters was defined. Critical control pins in the flexible fixture can be adjusted 0.5 mm in each direction. The adjustment changes the position for the ingoing parts in the assembly operation, Hereby we can we simulate process variations which appears in real production. These adjustments corresponds to the corrective actions the operator does when process variation disturbs the geometrical outcome of the assembled part to be outside given tolerances. Verification of that we can disturb the system to be outside tolerance can be seen in the table 1.

Table 1. Definition of corrective actions in the flexible fixture.

Pin name	Direction	change from default	X	Y	Z	Meas No
22	X	0,5	1137,138	528,013	736,68	1
22	X	-0,5	1136,138	528,013	736,68	2
19	X	0,5	1138,316	527,691	735,447	3
19	X	-0,5	1137,316	527,691	735,447	4
25	X	0,4	1176,83	771,737	714,23	5
25	Y	0,4	1176,43	772,137	714,23	6
25	X	-0,4	1176,03	771,737	714,23	7
25	Y	-0,4	1176,43	771,337	714,23	8
27	X	0,4	1176,738	- 771,447	734,981	9
27	X	-0,4	1175,938	- 771,447	734,981	10
27	Y	0,4	1176,338	- 771,047	734,981	11
27	Y	-0,4	1176,338	- 771,847	734,981	12

Example of measured deviation based on pin change can be seen in table 2 (Meas No 1 from table 1). The position of the measurement points can be seen in figure 3.

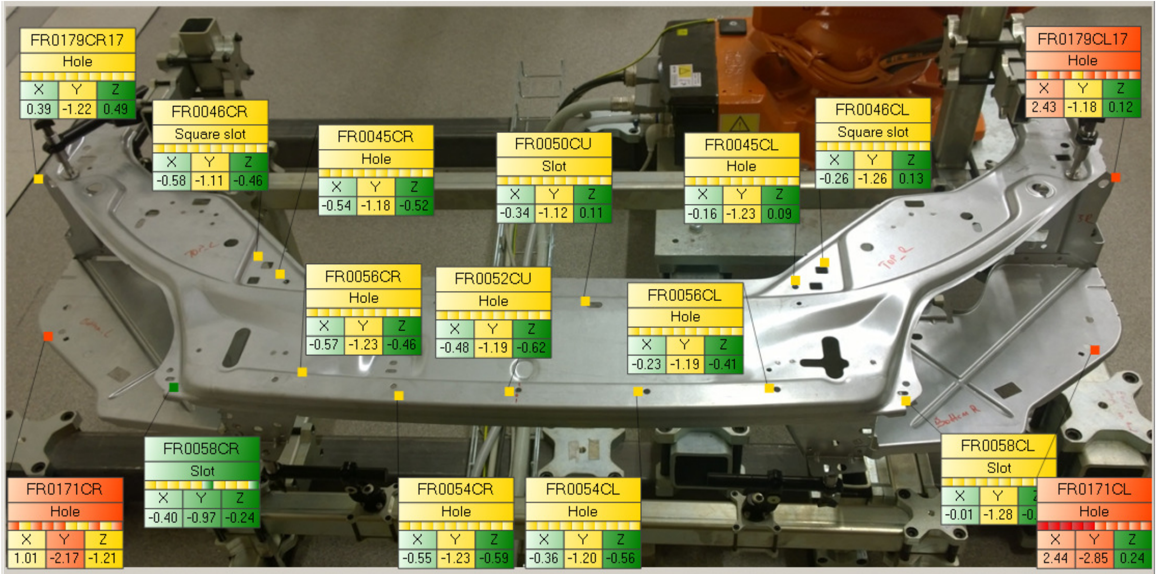

Figure 3. Position of measurement points.

Table 2 Measured results from Meas. No 1 in table 1.

	Deviation		
Feature Name	**X**	**Y**	**Z**
FR0050CU	-0,01	-1,185	0,039
FR0045CL	0,061	-1,371	0,13
FR0054CL	-0,033	-1,26	-0,414
FR0056CR	-0,055	-1,229	-0,239
FR0171CR	0,655	-1,103	-1,246
FR0046CR	-0,03	-1,181	-0,528
FR0179CL17	0,947	-1,295	-0,264
FR0052CU	-0,085	-1,268	-0,505
FR0045CR	-0,028	-1,265	-0,583
FR0056CL	0,012	-1,248	-0,307
FR0179CR17	0,562	-1,081	-0,264
FR0058CL	0,076	-1,333	-0,148
FR0058CR	-0,208	-1,139	-0,046
FR0054CR	-0,073	-1,277	-0,391
FR0171CL	1,996	-1,489	-0,08
FR0046CL	0,031	-1,247	0,299

In table 2, it clearly can be seen that the adjusted pin lead to geometry variation outside tolerance (±1mm). Hereby, it can be proven that by changing pin position, production like geometry variation outside tolerance which require process adjustment can be created.

5.4 Flexible tooling

Initially, a flexible tooling concept was conceptualized to provide a manual operation for general flexibility such as modularity and reconfigurability to handle product variations and aforementioned corrective actions. Then, in order to provide applicability to respective tooling solution, the concept was further complemented with affordability philosophy. Therefore, a general design solution consisting of a framework, reconfigurable units and pickups was developed. In this solution, a framework system, namely BoxJoint, was designed and built for easy and modular assembly/rebuilding. Furthermore, in order to negate lower accuracy built-up at BoxJoint, a reconfiguration module called Flexapod was also developed and manufactured (figure 4). Moreover, to facilitate fast and rapid configuration for corrective actions, a flexible *Plug&Play* mechano pin system was applied. In this system, affordability and quality were ensured through standardized components such as regular dowel pins and bushings (figure 4). Also, a control fixture that relies on the same design philosophy was also assembled. In this process, the framework was rapidly built by BoxJoint components where reconfiguration elements were chosen from mass manufactured products called D-Flex units (figure 4). In both assembly and control fixtures, the system can correspond to all corrective actions within mechanical limits through the help of an external measurement system; and since the assembly fixture is already calibrated with respect to a BIW coordinate frame, the immediate set up of the metrology system corresponds to 1-2 minutes depending on the operator experience.

Figure 4. Flexible tooling

5.5 Demonstrator cell

A demonstrator cell have been build at Chalmers (see figure 5).

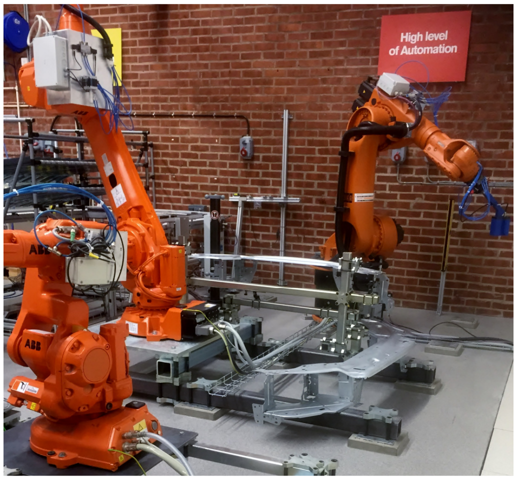

Figure 5. Demonstrator cell

The cell consist of one assembly station and one control station
Assembly station:
The assembly process is initiated by installation of the component called Cross in to the fixture by using 18 mm diameter pins. Later, loading of 6 vertical components is done via corresponding pins in 8 or 12 mm diameters. Then, loading is completed by the installation of horizontal parts. Later, the clamping procedure is conducted and spot welding (or tightening) process begins. Once the process is finished, clamps are released and the pins are removed from bushings. Consequently, the GOR becomes ready to be transferred to the control station.
Control Station:
In the control station, the assembled part is placed in a control fixture with fixed control pins to keep the part in position during measurement. The part is clamped into its position using the same clamping sequence every time. The robot based measurement system measure all defined control features and report their deviations as can be seen in figure 1.

MSA test of both the control fixture and assembly fixture have been done by using two different operator who have loaded the parts five times in the fixtures with approved results.

5.6 Delivery to FFI-goals

Fast and efficient geometry verification is required to sustain required quality of assembled products. Furthermore, an efficient geometry verification process together with and process adjustment procedure reduce the production lead time due to decreased need for adjustment outside the process flow and reduction of process disturbances. By flexible assurance processes, different parts can be quality assured.

AProC have developed efficient flexible methods for in-line geometry verification through the whole process chain – from feature definition via off-line programming to verification in measurement station.
Furthermore, methods and tools have been developed for process feedback based on the measured results as a reactive process. Hereby, corrective actions can be presented for the operator as a decision help for which process adjustment to be made.
All industrial process which involves assembly processes were geometry variations is based on individual part positioning can used the methods proposed in AProC.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The initiative ”Industry 4.0” is driving industry towards more automation and ”smart” solutions. AProC addresses research question which strives towards a self adjusting process which can react on geometry deviances and correct them before too much of the production volume is scrap.
FFI-projects such as GAIS and ToMM2 is also addressing questions in the same field – the intelligent factory. Furthermore, e.g. ARUM an project in EU:s 7th framework addressed also the question of the intelligent factories. There are several other projects and initiatives which addresses the question of technology for the intelligent factory. AProC is one piece in this puzzle which contributes to industry 4.0.

6.2 Publications

Ilker Erdem, Henrik Kihlman, and Alf Andersson, Towards Agility Oriented Flexible Tooling in Automotive Industry, The 23rd International Conference on Production Research , Aug. 2-5, Philippines, 2015

Ivan Tomasic, Peter Funk, Potential synergies between case-based reasoning and regression analysis in assembly processes, Workshop on Synergies between CBR and Data Mining at 22nd International Conference on Case-Based Reasoning (CBRDM'14), Sep 2014

Ivan Tomasic, Alf Andersson, Peter Funk, Automating a car production line adjustments by using case-based reasoning, Swedish Production Symposium 2014 (SPS 2014), Sep 2014

Hamidur Rahman, User Guide for AproC CBR system, internal technical report, Mälardalen University, Nov 2015

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Tomas Olsson, Ning Xiong, Elisabeth Källström, Peter Funk Fault Diagnosis via Fusion of Information from a Case Stream, 23rd International Conference on Case-Based Reasoning (ICCBR 2015), Sep 2015

Ning Xiong, Peter Funk, Tomas Olsson Representation and similarity evaluation of symbolic time series in uncertain environments, The Workshop on "Time in CBR" in the International Conference on Case-Based Reasoning (RATIC14), Sep 2014

7. Conclusions and future research

AProC have fulfilled all goals which were defined. Next step will be to continue to phase two in the project (AProCII) and connect the different WP with an automated solution.

In AProCII will the hypothesis:

“The geometry verification process and corrective actions can be automated and interact without operator adjustment to keep product within specification.”

be addressed.

To include other processes, it is required with more research regarding how to analyse signals from other systems e.g. milling and welding. By identifying signals form such systems and apply CBR-methods, these can also be monitored and automatic adjusted if parameters for corrective actions can be automated.

8. Participating parties and contact person

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